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Empirical evidences of dynamic speed limit impact on a metropolitan freeway

Josep Maria Torné[a,*], David Ramoneda[b], Francesc Soriguera[c]

[a]Center for Innovation in Transport, UPC-BarcelonaTech, Jordi Girona 29, 2-A, 08034 Barcelona, Spain
[b]Industrial Engineering School, UPC-BarcelonaTech, Av. Diagonal. 647, 08028 Barcelona, Spain
[c]Civil Engineering School, UPC-BarcelonaTech, Jordi Girona 1-3, building B1,office D-114, 08034 Barcelona, Spain

Abstract

The claimed benefits of dynamic speed limit (DSL) strategies (e.g. increase of throughput or speed homogenization) still remain as a controversial topic. The present paper presents an empirical assessment of DSL policies with aggregated traffic flow data.

A DSL system installed on the C-32 metropolitan freeway accessing the city of Barcelona (Spain) since February 2009 allows a before-after comparison between non-DSL and DSL scenarios. In order to achieve this objective, a new methodology is proposed. It includes speed-based data stratification for assessing the DSL drivers' compliance, detecting the causes which motivate drivers' behavior and the main DSL algorithms inefficiencies. In addition, a computation-friendly approach for searching stationary traffic periods is developed, differing from Cassidy (1998). The whole process permits to obtain a clear fundamental diagram characterization under DSL strategies.

The paper proves that when speed limits are lower than free-flow speed, the slope of the free-flow branch of the fundamental diagram is lowered proportionally. This implies that critical occupancies are higher than in their non-DSL analogues. Remarkably, almost any capacity increase is reported in the vicinity of the analyzed bottleneck.

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Keywords: Traffic flow, Dynamic Speed Limits, Drivers' behavior

* Corresponding author. Tel.: +34-934-137-204; fax: :+34-934-137-675.
E-mail address: josep.maria.torne@upc.edu

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1. Introduction

Speed limits are usually set to attempt to limit road traffic speed for several reasons (e.g. safety or pollution). When maximum allowed speed in a particular spot varies (manually or automatically) depending on traffic or weather conditions they are usually known as variable or DSL strategies. Control by means of variable speed signs was first introduced more than four decades ago in Germany (Zackor 1972). Because of its apparent simplicity and reduced implementation cost, nowadays, it is one of the most attractive policies and many cities around the world have introduced DSL systems, isolated or coordinated with other control measures. However, the effectiveness of the policy is still a controversial issue.

The claimed benefits of these actuations imply a reduction of traffic related emissions and accident rate, as well as an improvement in congestion reduction (e.g., reduction of stop&go traffic episodes or capacity increase). These claims result from studies mainly focused on control algorithms evaluated using second order traffic flow models (e.g. Hegyi et al. 2005; Carlson et al. 2010). However, few evaluations of the dynamic speed limit with real data can be found in the literature. Some exceptions include (Soriguera et al. 2013 and Papageorgiou et al. 2008). Real implementations of these DSL systems use somehow complex speed limit change algorithms, using different types of real time information. However, most of them are not sufficiently based on traffic flow behavior and lead to blind and inefficient algorithms.

There seems to be no agreement on the effect of DSL in aggregated traffic flow behavior. As many of the DSL benefits are originated in the microscopic traffic flow dynamics, only individual vehicle data or a smart use of aggregations allows observing certain phenomena. Unfortunately, micro data is not usually available, and previous results using aggregations are still non-conclusive. So, there is need to more empirical studies in order to obtain robust empirical facts which are expected to clear up the question. The present paper tries to fill this gap by presenting an exhaustive empirical analysis of the DSL effects only considering aggregated traffic data and current speed limits for a significant number of rush hour periods.

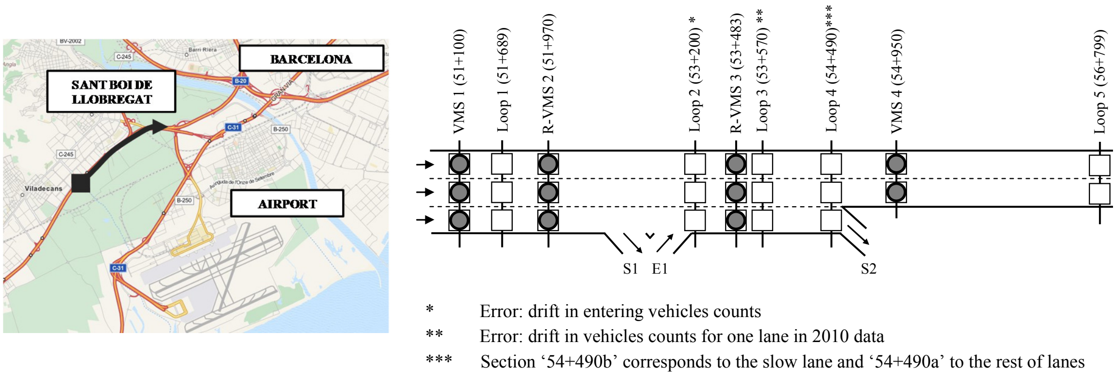
To address this evaluation, an empirical approach is proposed throughout the paper. First, Section 2 presents the motorway test site located in Barcelona, together with the available data and the methods proposed for data validation. The proposed methodology for the fundamental diagram (FD) calibration is described in Section 3. Meanwhile, Section 4 is devoted to analyze the obtained results focusing on the drivers' DSL compliance and its effect on the traffic flow characterization (Section 5). Finally, conclusions and avenues for further research are presented in Section 6.

2. The freeway site and available data

The freeway stretch selected for the test is part of the C32 freeway towards Barcelona with a length of approximately 5.7 km (Figure 1) containing two off-ramps and one on-ramp. The most downstream off-ramp (i.e. S2) triggers a bottleneck which creates recurrent congestion periods in the morning. Note that the mainline slow lane is devoted to S2 exiting ramp, producing a lane reduction in the trunk from three to two lanes. This fact justifies the test site location and sets a suitable frame for the proposed analysis. As a result, the fast lanes and the slow lane may be considered as belonging to different sections. Thus, they are named '54+490a' and '54+490b', respectively. For more details of the C32 freeway performance, it is recommended to check available literature (Soriguera, et al., 2013). The stretch is equipped with 5 loop detector stations (measuring the average speed, $v_{(s,t)}$, counting of vehicles, $n_{(s,t)}$, and occupancy, $o_{(s,t)}$, on a one minute basis) and 4 Variable Message Signs (VMS) gantries displaying dynamic speed limits (between V =40 and V =80 km/h), two of them (i.e. R-VMS 2 and R-VMS 3) also contain a radar installation.

Two speed limit regulation measures in C32 highway are analyzed. The first one came into force on January 1st 2008 limiting speeds to 80 km/h on major highways around Barcelona. The second one, applied one year later, was based on a dynamic speed limit management (DSL) maintaining the maximum speed limit of 80 km/h. Both considering 87 morning rush hour periods (from October 2008, February 2009, May and June 2010) and the presented speed limit regulations, three different scenarios are defined grouped by year criterion (i.e. 2008, 2009 and 2010).

Taking the original loop detector data, data presenting very unreasonable values of speed, occupancy or flow (such as negative or very extreme values) are not considered for further computations. With this procedure, around 5-6% of the original data are removed for further analysis, but many loops present less than 1% values (i.e. Loop 1 and 3).



(a) (b)

Fig. 1. – Test site: (a) overview map , (b) stretch layout indicating the different installations with its respective kilometer points and errors observed in the available data. Note: Figure 1(a) was obtained from © OpenStreetMap contributors, CC BY-SA.

3. Data analysis methods

Toward obtain an insightful macroscopic analysis of DSL effects with empirical data, different methodologies are sequentially applied to reduce the noise in the measures. Initial method steps begin with very broad data filters and getting more specific with each following step. Briefly, first step consists on a stratification of data available depending on its relative speed value with respect the current DSL. Next, the method tries to obtain as long as possible consecutive data intervals which verify some of the properties expected for stationary traffic states. These intervals become 'candidates' for being stationary traffic states. Finally, the stationarity of these 'candidates' is tested for systematically constructing bivariate diagrams under DSL conditions.

3.1. Data labeling and candidates' definition

A prime task to be tackled is exploring the effectiveness of DSL system. Recently, Long, et al. (2012) explore drivers perceptions in the implementation of a DSL system in St. Louis (USA) providing insightful facts which are coherent with the ones reported in the C32 case (Soriguera, et al., 2013). In fact, significant levels of dissatisfaction and resistance to innovation were observed, leading to lack of compliance with posted DSL speeds. Frequently, such resistance is based on perceptions of ineffectiveness and of high opportunity costs, strongly related with the drivers' perception of the value of time.

The next proposed methodology addresses these concepts in a simple way. To this end, data is stratified in three categories, ' C ', labeled as ' A ', ' B ' or ' C ' (depending on its relative value with respect to the set DSL: too high DSL value, DSL adherence and lack of DSL compliance, respectively) and considering a tolerance parameter named 'δ', which is set to 10 km/h. The former stratification combined with information about the posted DSL value and with the occupancy measurements forms a three components frequency vector, i.e. (o,V,i) being $i \in \mathrm{C} = \{\mathrm{A},\mathrm{B},\mathrm{C}\}$. The frequency of each vector occurrence allows obtaining many insights about drivers' behavior and the DSL governing algorithm. Section 4 analyzes the results for the different scenarios providing a full assessment for the DSL affectation and its compliance. In addition, the latter step has also provided certain time-series data belonging to different 'i' categories, being $i \in \mathrm{C}$ (see Figure 2 top), the 'candidates' to which the below stationary criteria will be applied. Now, the expected goal is to obtain long data spans where all the constituting shorter periods (i.e. 1-min data) verify to hold the same DSL value and most of them the same 'i' category. To that end, short periods, named as 'holes' and exhibiting 'i' values different than the ones of its surrounding intervals, are accepted. Figure 2 shows an example of two candidates of the same category with a hole between them which will become into a single candidate. '$T_{(i,j)}$' is defined as the time length of span 'j' and category 'i' computed as $T_{(i,j)} = \tau_{(f,j)} - \tau_{(o,j)}$, where '$\tau_{(o,j)}$' is the first time instant and '$\tau_{(f,j)}$' is the last time instant of span 'j', and $T_{(m,n)}$ is the duration of interval 'n' and category 'm' which is evaluated to be fused with span '$T_{(i,j)}$' and '$T_{(i,j+1)}$', such that $i, m \in \mathrm{C}$ and $i \neq m$. Then, if '$T_{(m,n)}$' is sufficiently short in comparison with $T_{(i,j)} + T_{(i,j+1)}$ and $T_{(m,n)} \leq T_{max}$, the hole is shifted to category 'i', so $T_{(m,n)} \subset T'_{(i,j)}$. Eq. (1) presents the condition to be verified:

$$T_{(i,j)} + T_{(m,n)} + T_{(i,j+1)} \leq (1+\alpha)\left(T_{(i,j)} + T_{(i,j+1)}\right) \tag{1}$$

Being $i \neq m$, $\alpha = 0.3$ and $T_{max} = 3$ min.

An special case arises when '$T_{(m,n)}$' matches with the first or the last interval of the rush hour time period. In that case, $T_{(i,j)} = 0$ and $T_{(i,j+1)} = 0$, respectively.

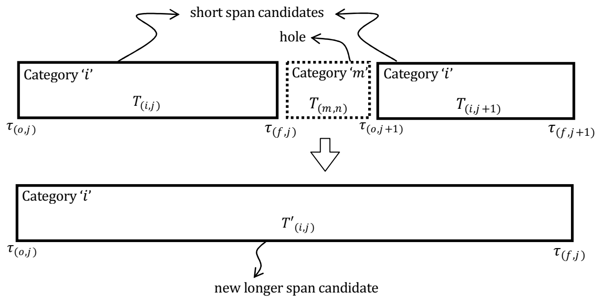


Figure 2 – Example of two candidate of the same category with a hole between them (top) next fused into one longer span candidate (bottom).

3.2. Construction of bivariate diagrams with near-stationary traffic data

It is known that, when traffic conditions are approximately stationary, reproducible bivariate relations exist, e.g. flow and occupancy. For this purpose, Cassidy (1998) defined the different steps involved in the construction of a bivariate diagram. However, its identification of nearly stationary periods by visual inspection of cumulative curves arises to be a non functional tool when big amounts of data are to be analyzed, as happens in the present case. The new approach is fully based on Cassidy's technique but differs on the way the stationary periods are detected by presenting a simple and robust method to replace the visual inspection procedure. Remarkably, it also differs from some fundamental diagram (FD) calibration methods (e.g. Dervisoglu, et al., 2009; Papageorgiou, et al., 2008). These methods considered non-stationary traffic conditions, thus the measurements obtained did not necessarily fallen on the curve describing near-stationary traffic, justifying the big dispersion regarded in their bivariate diagrams. The near-stationary condition helps to assure the obtained results mimic the representative behavior of a section, avoiding the non-stationary transition states.

As previously referred to, in the detection of the stationary traffic states lies one of the key points for well reproducing the different bivariate relations. These stationary time intervals will be obtained from inspecting the multiple candidates obtained from the previous method step. This inspection consists of verifying two criteria, one in relation to flow and the other affecting speed. If almost constant speed and flow values were encountered within the span, approximate stationarity can be accepted. In particular, flow is considered to be almost constant if the measured cumulative count do not deviate more than 'a' from cumulative count related to the average flow within the period, Eq. (2) and Figure 3.

$$\frac{\sum_{t=\tau_o}^{\tau_f} n_{(s,t)}}{\tau_f - \tau_o + 1} k\Delta t - a \leq \sum_{t=\tau_o}^{k\cdot\Delta t+\tau_o} n_{(s,t)} \leq \frac{\sum_{t=\tau_o}^{\tau_f} n_{(s,t)}}{\tau_f - \tau_o + 1} \cdot k\Delta t + a \tag{2}$$

Where ‘ a ’ is a parameter to be calibrated and $k = 1 \div \frac{t_f - t_o + 1}{\Delta t}$.

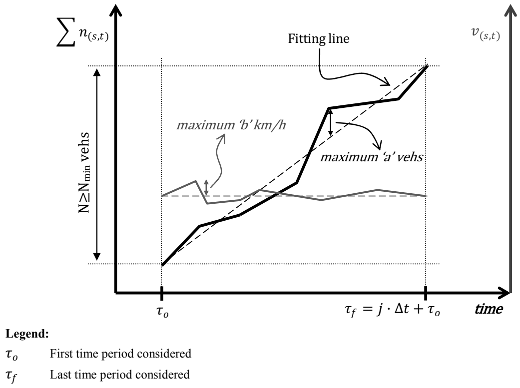


Figure 3 – Detecting stationarity from vehicle cumulative count.

The second stationarity criterion deals with speed measurements. Being at least ‘ N_{min} ’ aggregated vehicles, speed was considered to be almost constant during the whole span considered, if the average speed of all the constituting shorter periods ‘ t ’ (see Eq. (3)) was contained within the confidence interval limits plus an additional value, ‘ b ’, of each particular measurement.

$$\frac{\sum_{t=\tau_o}^{\tau_f} n_{(s,t)} \cdot v_{(s,t)}}{\sum_{t=\tau_o}^{\tau_f} n_{(s,t)}} - v_{(s,t)} \cdot e_{V_{(s,t)}} - b \leq v_{(s,t)} \leq \frac{\sum_{t=\tau_o}^{\tau_f} n_{(s,t)} \cdot v_{(s,t)}}{\sum_{t=\tau_o}^{\tau_f} n_{(s,t)}} + v_{(s,t)} \cdot e_{V_{(s,t)}} + b \tag{3}$$

Where ‘ b ’ is a parameter to be calibrated and $e_{V_{(s,t)}} = \sqrt{\frac{CV_V{}^2}{n_{(s,t)}}}$ considering a 67% degree of confidence, being ‘ CV_V ’ the speed coefficient of variation taken as 0.1375 (Soriguera & Robusté, 2011).

Finally, for obtaining large stationary periods, the algorism aggregates as much vehicles as possible while Eq. (2) and (3) continue to hold. Once the process has finished, it is expected that multiple stationary states would have been obtained with reasonable time durations of at least 3-4 min, as proposed by Cassidy (1998). Every stationary state lasts for ‘ T ’ minutes, aggregates $N \leq N_{min}$ vehicles, belongs to one particular ‘ C ’ category and exhibits a unique V -value. Once the aggregations have been computed, bivariate plots are depicted considering the mean occupancy and flow values of all the stationary spans considered.

4. Drivers’ compliance and algorithm accuracy assessment

Remember that, for every section and year, a three component (i.e. $(o,V,\ i)$ being $i \in \mathrm{C} = \{\mathrm{A,B,C}\}$) frequency matrix is obtained. To simplify the results interpretation, different manipulations are done. First, the 3-dimensions matrix is reduced to 2-dimensions by stratifying according to category, ‘ C ’. Second, data is manipulated in such a way that, for a given (o,V) pair of values, section and year, the addition of every normalized frequency rate across all ‘ C ’ categories results equal to 100% (i.e., $\sum_{i \in C} (o, V, i) =$ 100%).

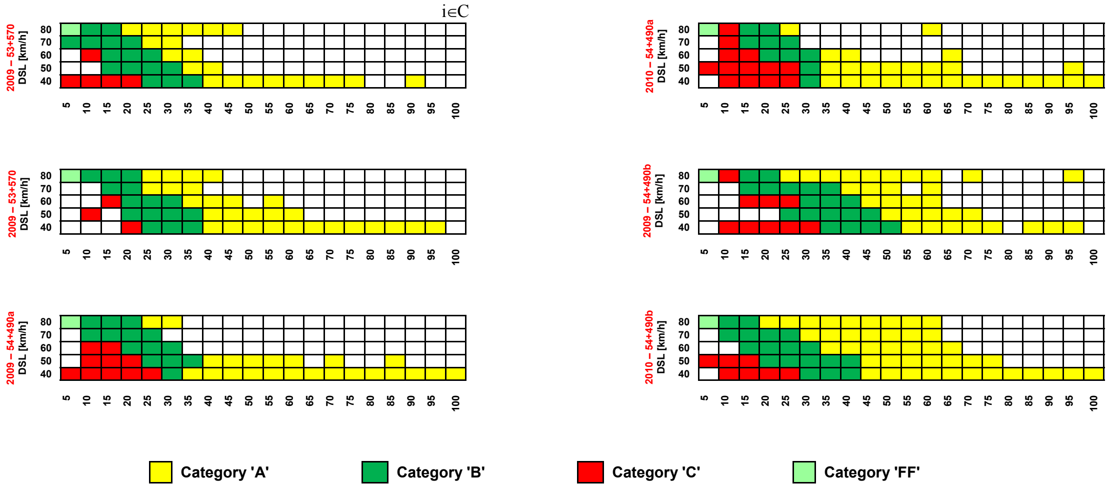


Figure 4 – Zone distribution of the four considered categories for sections 53+570, 54+490a and 54+490b, in years 2009 and 2010.

In that way, different patterns can be observed depending on the category. For a given (o,V) pair, big percentage values in category ‘ A ’ mean malfunctioning in the DSL algorithm, which is greatly influenced by the relative position between the particular loop and the VMS gantry. If considering category ‘ B ’, it is desirable to find big percentage values. In fact, the higher the value, the better the algorithm efficiency and the drivers’ DSL observance. However, category ‘ C ’ may shade interesting information about the lack of DSL compliance and its capability to act as a mainline metering. To this end, two effects will be studied (i) the effect of the distance between the loop localization and the radar installations and (ii) the trends for the region with low values of ‘ o ’ and ‘ V ’. For visualization purposes, every particular cell is colored depending on the category presenting the higher frequency values for that particular (o,V) pair (see Figure 4). In that case, the categories considered are ‘A’, ‘B’, ‘C’ and a new specific category, named ‘FF’, corresponding to cases where $o \in [0,5]$% and V =80 km/h. It captures the free-flow state before the onset of congestion, no matter which is the corresponding category. In short, this method provides a useful snapshot of the drivers’ behavior in a certain section under all traffic conditions. Results will be showed for three representative sections: one highly influenced by a radar installation (i.e. section 53+570 containing Loop 3 installation) and the other two are located far away from the radar influence (i.e. sections 54+490a and 54+490b). To easily compare results, cells exhibiting different categories across the two years available are highlighted with thick line borders in Figure 4.

A first glance at Figure 4 reveals a clear pattern for each of the depicted zones, no matter neither the section nor the year. Zone ‘B’, which mainly contains category ‘B’ states, sketches a linear tendency with negative slope of around 15%-occupancy wide values, covering from 0% up to 35-50% occupancy values, depending on the sections. In fact, this shape is coherent with the common empirical results obtained when plotting occupancy against speed. Zone ‘C’, mainly containing category ‘C’ states, takes the remaining zone below the green one, i.e. low DSL and occupancy values. Finally, zone ‘A’, mainly containing category ‘A’ states, is irregularly spread above the zone ‘B’ and in general, is observed for low DSL and high occupancy values.

Focusing on section 53+570, it must be noted that most of data inside zone ‘B’ and ‘FF’ belongs to category ‘B’. In absolute values, only a 2-4% of the total data belongs to ‘C’. It shows the big effect of proximity to the radar installation (installed around 300m upstream of the section). Zone ‘B’ shape is quite homogenous with a maximum occupancy around 35% value for both years. However, on year 2010, a shift in the zone ‘B’ border to higher occupancy value is observed, probably induced by drivers’ accommodation to the new technology which leads to speed limit observance in more dense traffic conditions. Remarkably, a high rate of category ‘A’ data is also observed, i.e. around 20% of total data for 2009, within zone ‘A’ and ‘B’. These values are two times higher than the ones observed in 54+490a section. This behavior may be imputed to the 2 km distance between the section and its DSL governing 'R-VMS 2' gantry. It means that the algorithm miscalculates the traffic flow evolution along this distance, leading to inappropriate DSL values.

If considering section 54+490a, only up to 6% values are obtained. In that case, the section is governed by 'R-VMS 3', only 1 km upstream the referred section. This result well fits to the fact of being located immediately downstream of the bottleneck localization, far away from the closest radar installation. Moreover, zone 'B' band is quite narrow if compared to other sections. If focusing on zone 'FF', the lack of DSL attainment can be verified: data is distributed 40% category 'B' and 60% for category 'C' on year 2009, whereas 20% and 80% on 2010, respectively.

Finally, section 54+490b arises as a special section case, due to the fact of being a section devoted to exiting vehicles through 'S2'. It is well reflected in the high rate of speed limits fulfillment (i.e. high category 'B' and low category 'C' percentage values) and the lack of vehicles within zone 'FF'. In essence, the section only behaves in two different modes: (i) in free-flow conditions few vehicles cross the section (it corresponds to one slow lane located at the kilometer post 54+490), which justifies the lack of data for occupancy up to 10% values on 2009; (ii) in congested conditions the vehicles exhibit low speed values, which increases the percentage of category 'A' vehicles for certain DSL values (i.e. around 18-30% of the total data, high if are compared with section 54+490a results exhibiting 3-6% values) or increase the percentage of category 'B' when the DSL value lowers, as can be observed in the zone 'B' band wide which considerably increases for low DSL cases.

5. Evaluation of DSL effects on freeway traffic

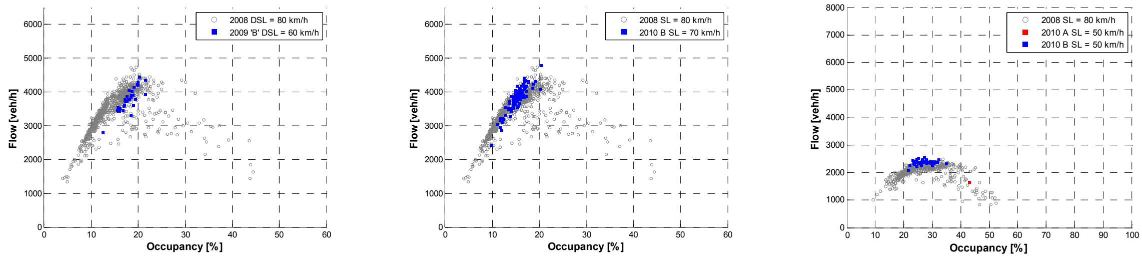
Certainly, one crucial issue remains to be addressed: to quantify the DSL impact in the freeway maximum flow observed (i.e. capacity) and its critical occupancy. It is addressed thanks to the methodology described in Section 3, leading to insightful results about the DSL contribution. Two different DSL-controlled scenarios outcomes (i.e. year 2009 and 2010) will be compared with the non-controlled scenario (i.e. year 2008), considering all the included sections, except 53+200 due to a systematic drift counting error detected. It should be noticed that the posed method only considers stationary states in the bivariate diagrams construction step. They closely depend on three parameters: 'a', 'b' and 'N_{min}', which were carefully calibrated resulting a=10 veh, b=7 km/h and N_{min}=125 veh. In this way, multiple bivariate diagrams (i.e. '$\hat{o}$' vs '$\hat{q}$') stratified by different criteria (i.e. V-value, category and year) were obtained.

5.1. Effects on freeway capacity

For every year, speed limit and section, the maximum flow states are detected from the bivariate diagrams. Remarkably, all of them correspond to stationary states of at least 3-6 min long. In the light of the maximum flow values obtained, it might be concluded that DSL strategy has no effect on increasing the capacity in a particular freeway section. Actually, the scatter of points corresponding to category 'B' in DSL-controlled scenarios, frequently exhibits maximum flow values below the non-controlled ones (Figure 5a and 5b), although for certain $V \leq 80$ km/h cases no significant capacity decrease is observed when the controlled case is compared with the uncontrolled one (Figure 5c).

The discharge flow is the suitable indicator for the capacity of a bottleneck section. Although many locations presents congestion episodes, only one section is located immediately downstream of the bottleneck. So, section 54+490a arises as a suitable location for capturing the representative capacity value of the congested test site stretch. Then, it is expected that under the DSL strategy certain bottleneck discharge flow increment would be observed. Unfortunately, this assumption is not verified (see Figure 5a and 5b). No evidences support the DSL hypothetical capability to increase the bottleneck discharge flow.

Another interesting conclusion may be drawn referred to section 54+440b. Remember this section is devoted to an exit ramp, S2. Focusing on year 2009 results it can be observed that almost no maximum flow increment is observed in the section due to the DSL policy. This result is coherent with the fact that DSL cannot influence in the off-ramps capacities, which are only constrained by structural factors or downstream traffic conditions (e.g. roundabouts, urban network…). However, year 2010 results seem to contradict the latter assertion, because a little increase is reported for the referred section (Figure 5c). Two arguments can shed some light to the issue. First, the fact that, for years 2008 and 2009, the conservation of the flow principle is verified among sections 53+570 and 54+490a/b capacities. That is, the addition of the two most downstream sections capacities exhibit close values with respect the 53+570 section capacity value. Second, the capacity value for section 53+570 remains almost constant among the two DSL-controlled scenarios, exhibiting a constant maximum flow value of around 6600 veh/h. If considering both facts together, it is reasonable to conclude that an increment in the off-ramp of around 12% is produced at S2 off-ramp. It may be motivated by a variation on the drivers' routes preferences, a structural improvement on the off-ramp or any other downstream element of the network, but no evidences can support this increment has been motivated by DSL strategies.



(a) (b) (c)

Figure 5– Bivariate diagram for section 54+490a (a) V =60 case on year 2009, (b) V =70 case on year 2010 and (c) for section 54+490b V =50 case on year 2010.

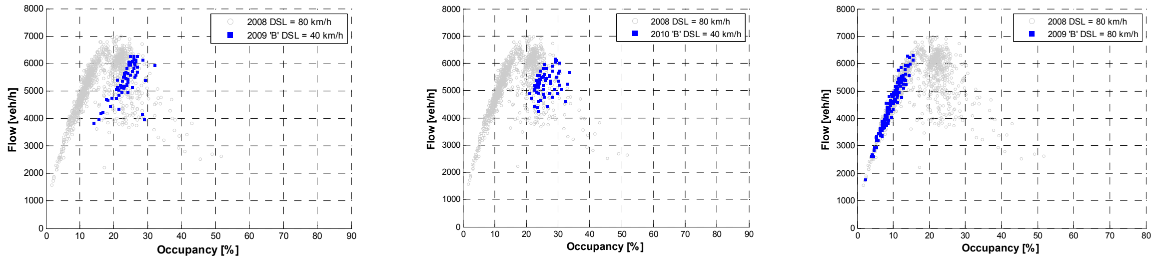
5.2. Effects on critical occupancy

To better capture the critical occupancy, 'o_{crit}', variation within the closed congested stretch preceding the bottleneck location (i.e. between E1 location, around kilometer post 53+200, and S2, around kilometer post 54+490), the most representative section must be suitably selected. In that case, and in contrast with the capacity estimation, for the critical occupancy calibration it is recommended to analyze data inside the congested stretch, not downstream it. This is justified by the fact that in section 54+490a, almost no data belonging to the congested branch is observed. So, sections 53+200 and 53+570 may be a suitable election. However, these sections presents drift counting errors which produce an overestimation of the 'o_{crit}' values, except for year 2009 data in section 53+570 (Figure 6a and 6c).

The obtained results show a clear tendency to increase the 'o_{crit}' value when lowering the speed limit (see Table 1). The FD free-flow branch slope is lowered proportionally to the speed limit value, shifting the 'o_{crit}' to higher values. In this way, DSL-induced critical occupancies are higher than their non-DSL counterparts. Note that for the scenarios containing errors, the absolute values must be considered overestimated, while the relative ones may still be valid for descriptive purposes. In particular, increments up to 45% are found for $V = 40$ cases in section 53+570 on year 2009 Figure 6a and 6b presents the bivariate diagram for flow and occupancy variables for the latter section on years 2009 and 2010, respectively. With this scatter representation, the 'o_{crit}' value can only be roughly determined, thus the usefulness of the data fitting process which helps to improve the FD characterization. Unfortunately, data only covering a thick range of occupancy values is observed for high V-values and may lead to a biased 'o_{crit}' estimation. Examples can be found for $V \leq 70$ m/h cases in section 53+570 on year 2009, where unrealistic negative increments are captured. Figure 6c shows the $V \leq 80$ m/h case for year 2009 where it can be clearly observed how the points do not reach '$\mathrm{o}_{\mathrm{crit}}$' values corresponding to year 2008 case, thus non representative 'o_{crit}' estimations of '$\mathrm{o}_{\mathrm{crit}}$' are obtained.

Table 1– Variation of 'o_{crit}' with respect year 2008 case, for all the speed limits values and two DSL-controlled scenarios, only considering stationary states belonging to category 'B'.

		'o_{crit}'[%]	'o_{crit}' variation with respect year 2008 [%]				
Section	Year	Year 2008	40	50	60	70	80
53+200	2009	*27,15*	26,03	36,75	-18,68	3,11	-22,75
	2010		21,39	17,98	13,34	-22,82	-41,27
53+570	2009	*22,11*	45,49	16,64	14,58	-22,99	-45,72
	2010		20,78	19,29	16,91	-4,45	-28,15



(a) (b) (c)

Figure 6– Bivariate diagrams and fundamental diagram calibration in section 53+570 (a)-(b) for V =40 case and (c) for V =80 case for year 2009.

6. Conclusions and further research

Despite the considerable interest and the intense debate among the scientific community in the DSL strategies, the effectiveness of this policy is still a controversial issue. The empirical approach which has been presented in the paper aims to have illuminated the issue. In short, the macroscopic results show restricted benefits for DSL strategies, being necessary speed compliance scenarios. It means enforcement plays a crucial role for the effectiveness of such strategy. However, DSL is not capable to increase the throughput across bottleneck sections, but to increase the critical occupancy and thus, generating more packed vehicle platoons.

The first speed based data stratification has provided an enriching insightful about the driver's behavior when facing this kind of active traffic management (ATM) strategies, few times tackled in the literature. At the same time, this step has allowed to identify spans affected by the DSL strategy susceptible of being classified as stationary periods. Next, the new methodology for searching stationary periods has resulted an efficient approach, easily translatable into computational languages, as it avoids the use of any visual inspection tool. The whole process has permitted to obtain a good FD characterization under DSL strategies.

The critical occupancy calibration is one of the most important outputs derived from the latter issue. In fact, when lower than free-flow speed values are set in a section, the FD free-flow branch slope is lowered proportionally. In that way, DSL affected critical occupancies are higher than their non-DSL analogues. However, an inherent difficulty arises when analyzing DSL effects for certain speed limitations. As data collected during specific speed limit values may not cover the whole range of possible occupancies, conclusions related with capacity increase or critical occupancy shift could be difficult to be drawn in such cases. This is the case for high speed limit values (e.g. 80 km/h), where the existence of big percentages of speeding vehicles makes the scatter plots to be truncated at low occupancy values. Such inconvenience would only be solved in scenarios where a particular DSL value is fixed from the onset to the offset of the rush hour episode (e.g. Soriguera & Sala 2014).

The DSL effect on freeway capacity has been addressed. However, no empirical capacity increment is seen in congested periods. It means the DSL strategy is not capable to improve the freeway performance in the vicinity of active bottlenecks. Mobility improvements may be obtained when combined with another active traffic management strategy, e.g. ramp metering (Carlson et al. 2010, Hegyi et al. 2005 and Torné et al. 2014).

Certainly, many issues remain for further research. First of all, individual vehicle data is needed. The availability of such database would lead computing lane changes maneuvers, characterizing reliably speed and occupancy vehicles distributions along the section, obtaining insights about DSL contribution to cut down traffic instabilities or capturing microscopic variables distributions, for instance, vehicle headway or spacing. Anyway, it would be helpful to develop a similar analysis in a different DSL installation in order to avoid site and algorithm specific results.

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